



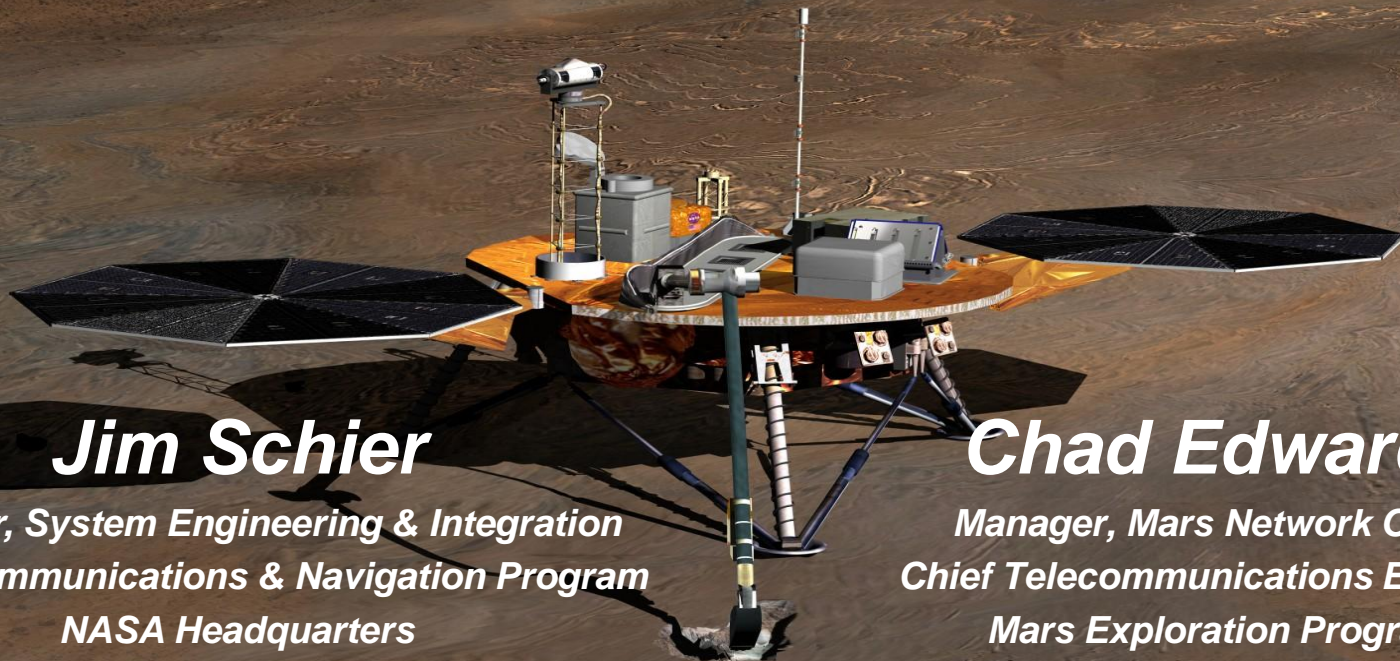
NASA's Mars Telecommunications: Evolving to Meet Robotic and Human Mission Needs

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Agenda



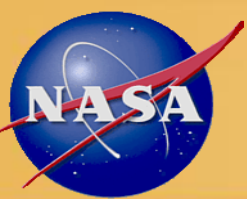
- **Architecture / Capabilities**
 - Past
 - Present
 - Near term
 - Far term
 - Lunar Architecture
- **Progress**
 - Software Defined Radios (SDR)
 - Solar System Internet (SSI)
 - Optical communications
- **Summary**



Past : *Project Mars: A Technical Tale* by Wernher von Braun, 1949

- “Here’s the communication story. We must consider three separate types of radio communication.
 - “The first type is for intership work...not much different from the 2-way command sets used between airplanes...
 - “The second type is for middle distances of about 10 to 20,000 miles...primarily for communication with the landing party when the space ships are circling Mars. These middle distance transmitters will draw about 5 kW each...
 - “But the third and most problematical radio is ranges. ...Communication across hundreds of apparently calls for concentrating the radio energy in a small divergence. The radio boys are still pretty sure of this. ... it seems quite definite that these High Power Transmitters have to be separate from the ships, not only sources of power.
- “The Congress has voted us our whole two billion dollars! Boys, we’re off in a cloud of dust!” *It’s 1980.*





Today: Mars Relay Network

Odyssey (ODY)



NASA

Launched 2001

Orbit:

- 400 km sun-synch
- 93° inclination
- ~5 AM asc node

Deep Space Link:

- X-band
- 1.3 m HGA
- 15 W SSPA

Relay Link:

- CE-505 UHF Transceiver
- 8, 32, 128, 256 kbps
- CCSDS Prox-1 Protocol

Mars Express (MEX)



ESA

Launched 2003

Orbit:

- 250 x 10,142 elliptical
- 86° inclination
- Non-sun-synch

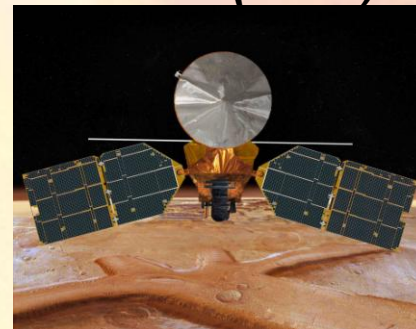
Deep Space Link:

- X-band
- 1.65 m HGA
- 65W TWTA

Relay Link:

- Melacom UHF Transceiver
- 2, 4, ..., 128 kbps
- CCSDS Prox-1 Protocol

Mars Reconnaissance Orbiter (MRO)



NASA

Launched 2005

Orbit:

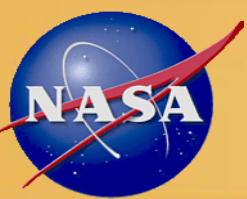
- 255 x 320 km sun-synch
- 93° inclination
- ~3 PM asc node

Deep Space Link:

- X-band
- 3 m HGA
- 100 W TWTA

Relay Link:

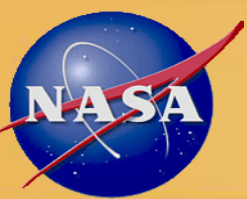
- Electra UHF Transceiver
- 1, 2, 4, ..., 1024 kbps
- CCSDS Prox-1 Protocol



Phoenix Relay Support

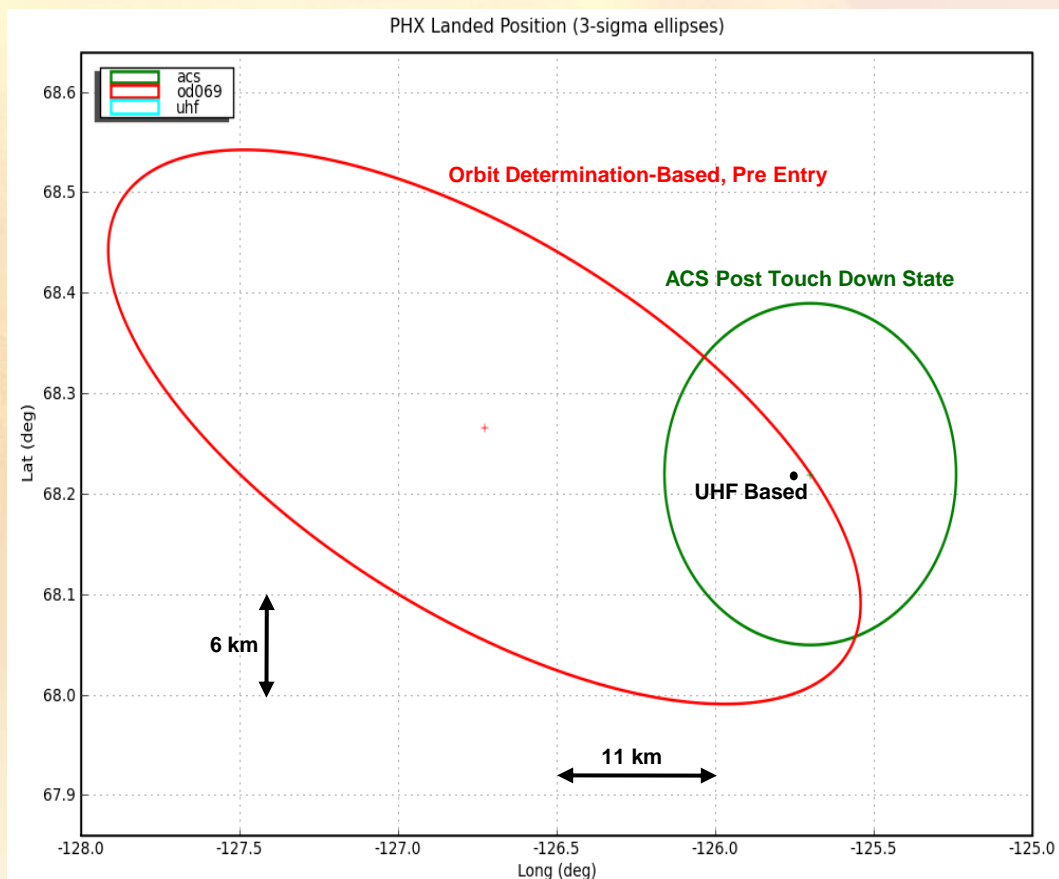
- ***UHF relay support was key to mission success***
 - **Entry, Descent, & Landing (EDL)**
 - 4 UHF links (ODY, MRO, MEX, and Green Bank 100m) provided extensive info during critical event
 - 1st use of Electra open-loop recording with post-processing to recover EDL carrier *and* telemetry
 - 32 kbps – highest critical event comm telemetry rate
 - **Surface operations**
 - UHF-only mission – no Direct To Earth link from surface
 - Large data volume @ low energy-per-bit – ODY and MRO returned >38 Gbits of data
 - 4x required data return/sol – average of 251 Mb/sol
 - First operational use of Electra UHF Transceiver on MRO





Relay Links for Navigation

- Measurements of the Doppler shift on the UHF signal during a relay pass provides a precise determination of a lander's position in the Martian reference frame
- *Phoenix Lander position knowledge based on pre-entry tracking had an uncertainty of ~30 km*
- *Including inertial measurements made during entry & descent improved position knowledge to ~10 km*
- *After a few UHF relay passes, the Doppler-based position uncertainty was reduced to < 30 meters*





An Added Bonus from EDL Comm...

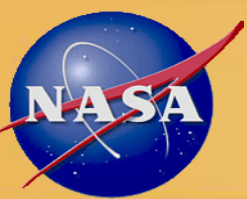




Looking Ahead to Curiosity

- **The 2011 Curiosity Rover will significantly advance Mars relay capabilities**
 - **Curiosity-MRO link will fully exploit Electra capabilities**
 - Data rates up to 1 Mbps
 - Adaptive Data Rate algorithm for autonomous control of return link data rate based on actual channel characteristics
 - 250 Mb/sol data return spec (5x the MER-ODY spec) is well-matched to high-rate Curiosity science instrument suite

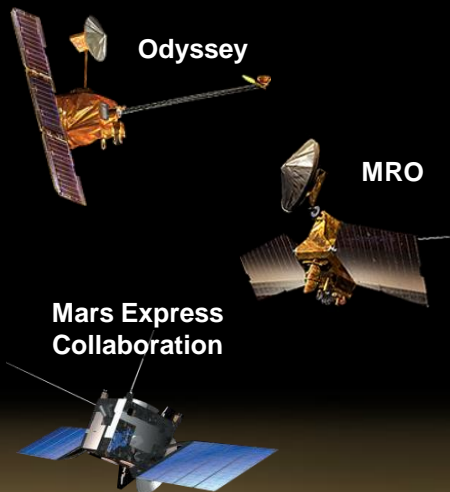




Beyond Curiosity: NASA-ESA Mars Exploration Joint Initiative

← NASA-ESA Joint Mars Initiative (in final planning) →

**Operational
2001-2009**

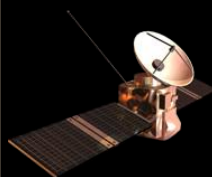


2011

Curiosity
Mars Science Lab

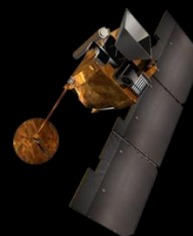


2013



MAVEN
Aeronomy
Orbiter

2016



ESA-NASA
Trace Gas
Mapper
(+ telecomm.)

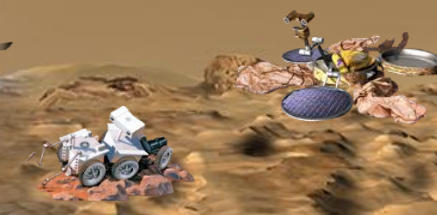
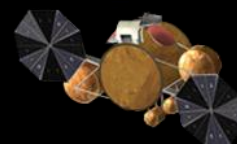
2018

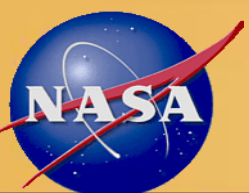
NASA and ESA
Rovers
(Astrobiology/
Sample Return
Tech. and
ExoMars)



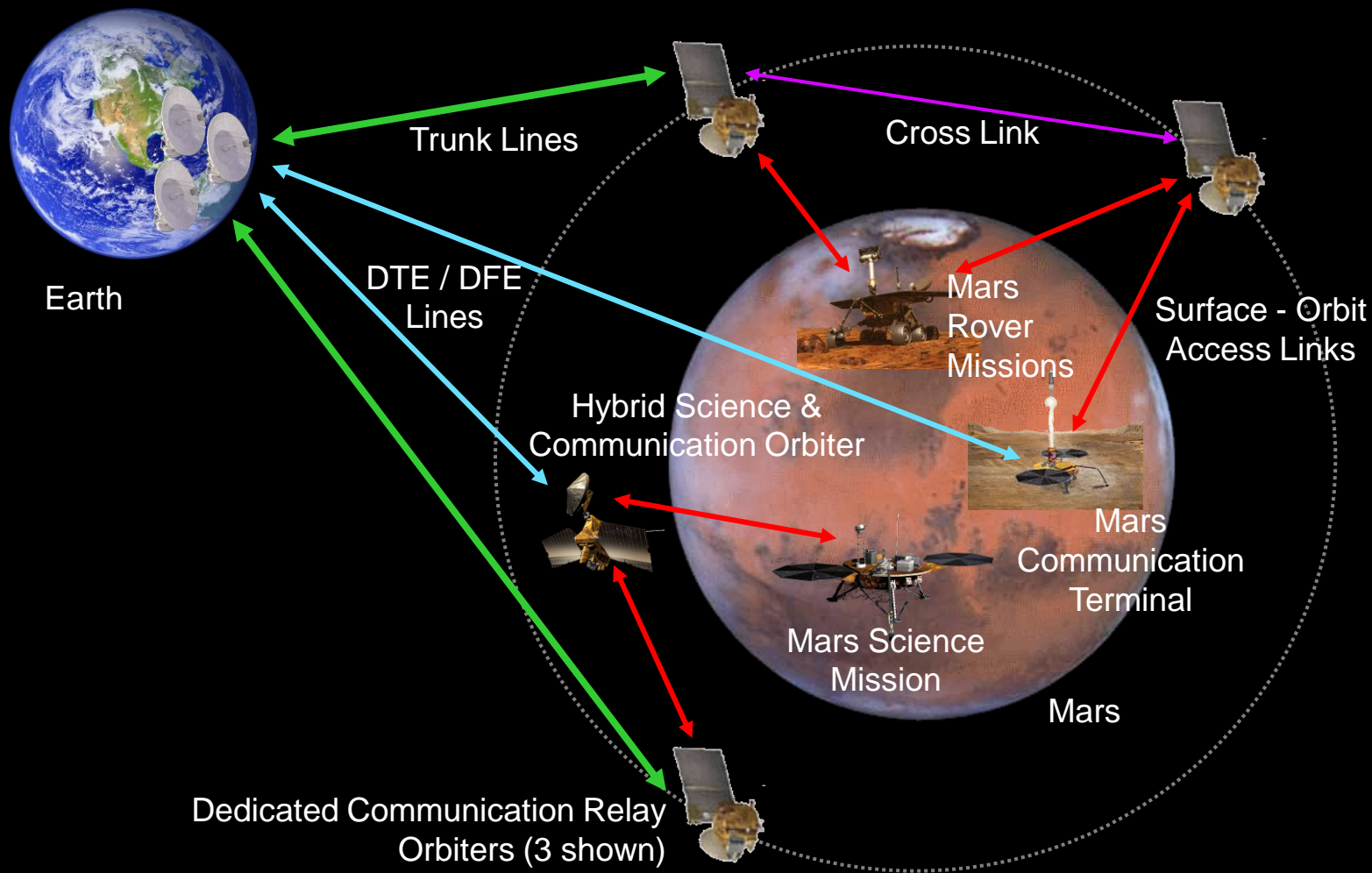
2020 & Beyond

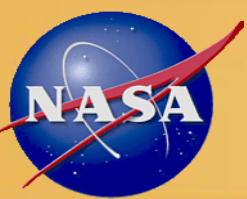
The Era of Mars
Sample Return





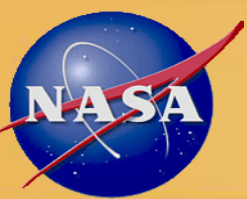
Mars Communication Architecture 2025



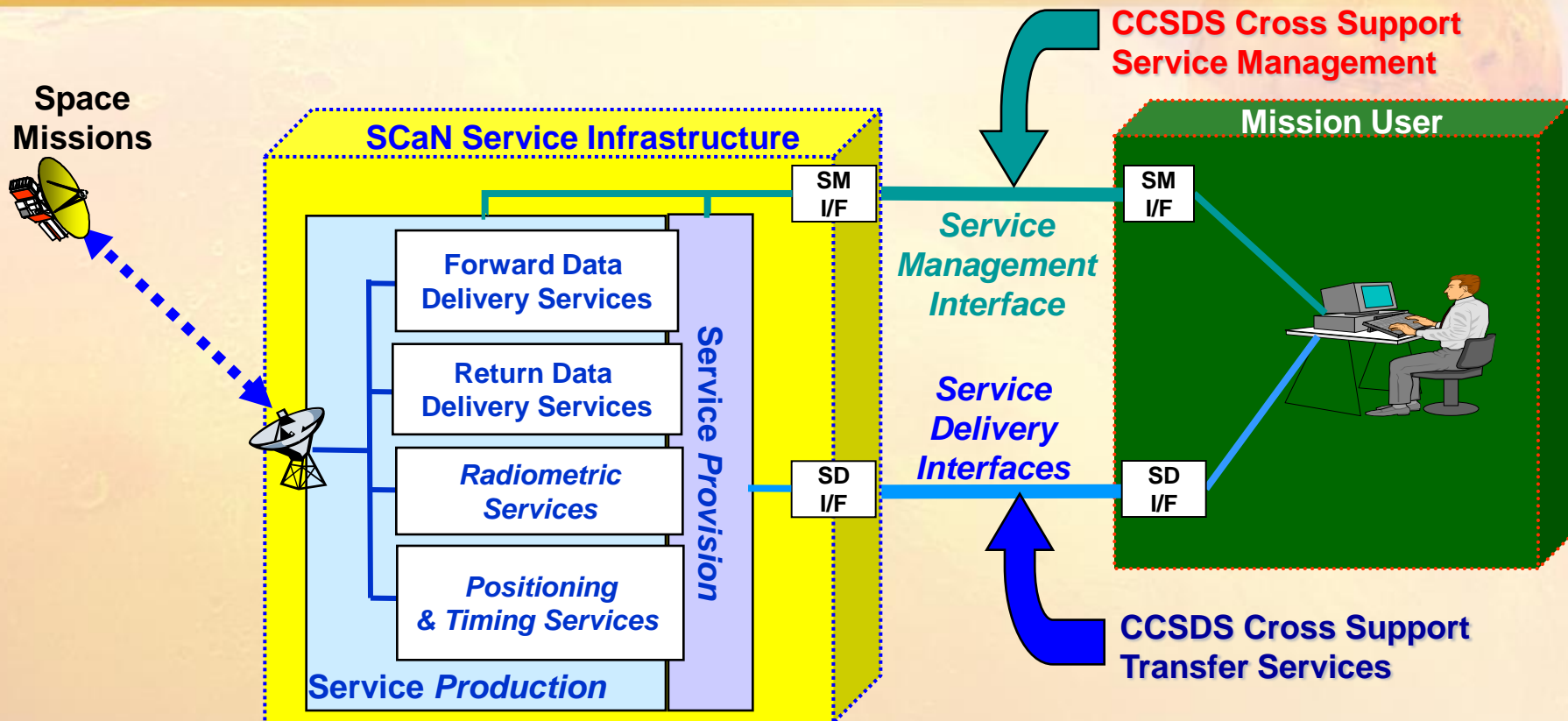


Mars Architecture Characteristics

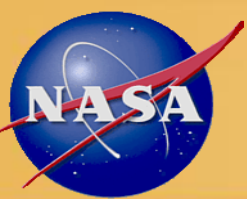
- **Optical (laser) comm with 100 Mbps return link at 1 AU; > 2 Mbps forward**
 - Extensible to 1 Gbps
- **RF: Up to 6 Mbps data rates (near-term) & 150 Mbps (long-term) using 32 GHz Ka-band**
- **New tracking data types for precision navigation using Ka-band & Optical**
 - Entry, Descent & Landing + Surface navigation
- **Robust, scalable, flexible antenna array**
- **Solar System Internet (SSI)**
- **Robust emergency X-band TT&C**
- **Standard services on all networks**



Standardized User Interfaces



- All missions will have the same interfaces for service management & execution using international standards for interoperability. Benefits:
 - Fewer control centers needed
 - Increased use of COTS
 - Easier mission planning & cross-support from non-NASA networks
- ⇒ Lower cost



Mars Communication Architecture 2030+

Surface Elements:

- Fixed: Habitat, Science packages, ISRU plant
- Mobile: Robotic rover, Crew rover, EVA crew

Mars Relay Satellite (MRS)

Orbiting Elements



Network Link Frequencies (GHz)

- ↔ 40/37 Ka (Earth Trunk High Rate)
- ↔ 2.4-9 (TBD) 802.xx (MCT Network)
- ↔ 32/34 Ka (Proximity High Rate)
- ↔ 7/8 X (Proximity Low Rate)
- ⋯ 7.2/8.4 X (Earth Trunk Low Rate)
- Hardwired (fiber)

Lander

EVA Crew

Crew Rover

Mars Comm Terminal (MCT)

Habitat

Robotic Rover

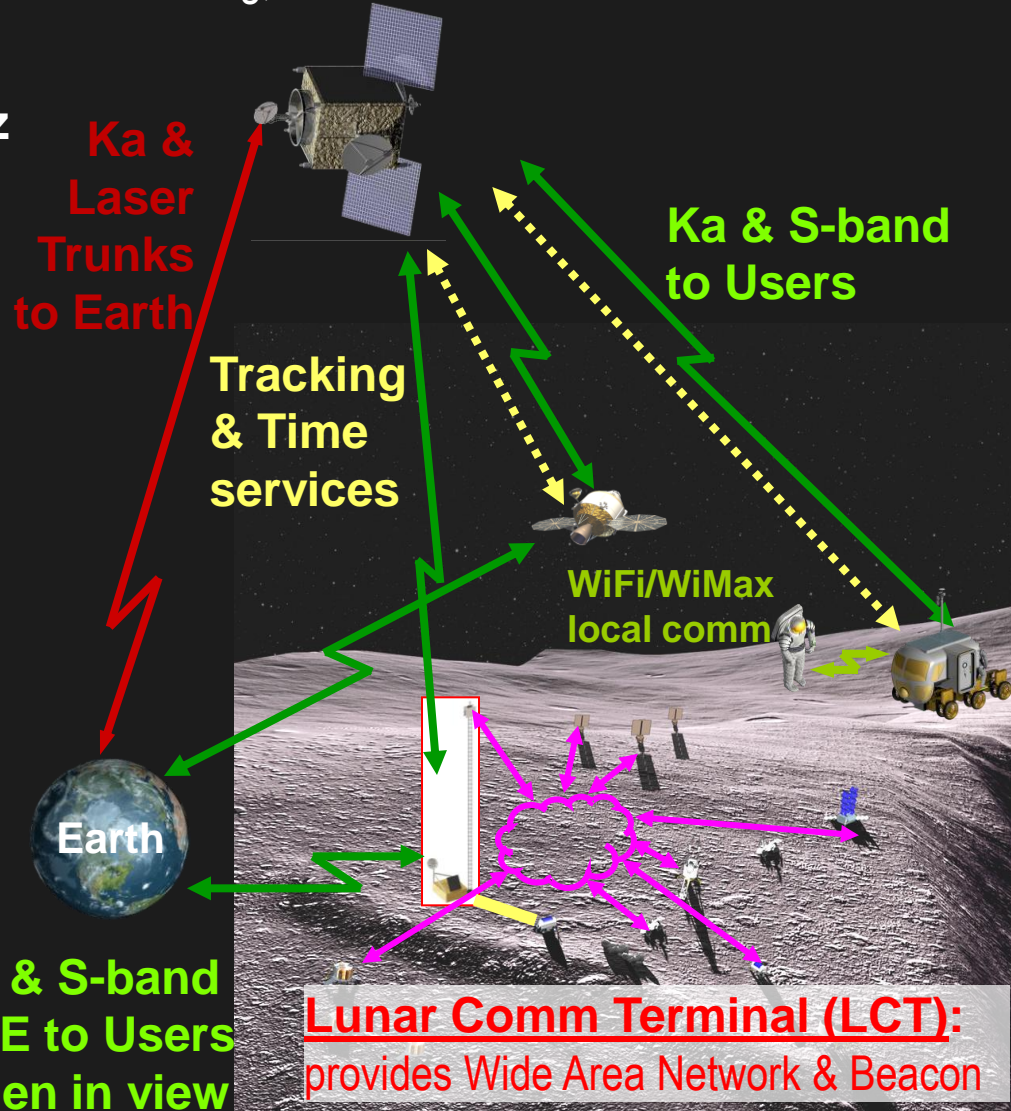
Science Package

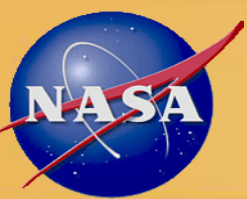


Lunar Architecture Features:

- Optical (laser) comm with 1 Gbps return rate; 100 Mbps forward
- RF: Up to 250 Mbps return data and 100 Mbps forward data using 40 GHz Ka-band
- New tracking data types for precision navigation using Ka-band & Optical
 - Descent & Landing + Surface nav
 - Atomic clock on LRS & LCT
- Robust, scalable, flexible antenna array on Earth to meet varying planetary needs
- Solar System Internet (SSI)
 - Lunar Local Area Networks fully networked with Earth via LRS/LCT
 - Standard services on all networks
- Robust emergency S-band TT&C

Lunar Relay Satellite (LRS): Coverage of Outpost & rest of Moon with comm, tracking, & time services



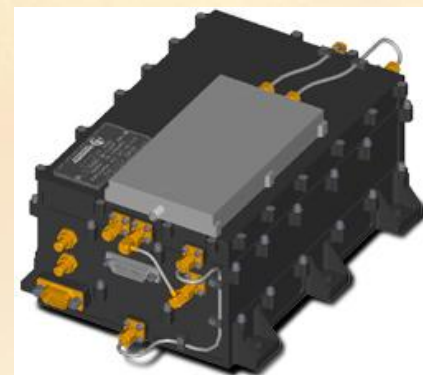


Electra Proximity Link Radio

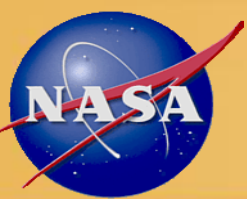
- **Electra software-defined radio (SDR) provides flexible platform for evolving relay capabilities**
 - Electra payload onboard Mars Reconnaissance Orbiter
 - Electra-Lite payload in development for Curiosity with 40% mass/volume reduction
- **Key Electra features**
 - CCSDS Proximity-1 Link protocol for interoperable, reliable data transfer
 - Frequency-agile operation across UHF band (390-450 MHz)
 - Integrated Doppler navigation and timing services
 - Fully reprogrammable software/firmware functionality



Electra UHF Transceiver



Electra-Lite UHF Transceiver



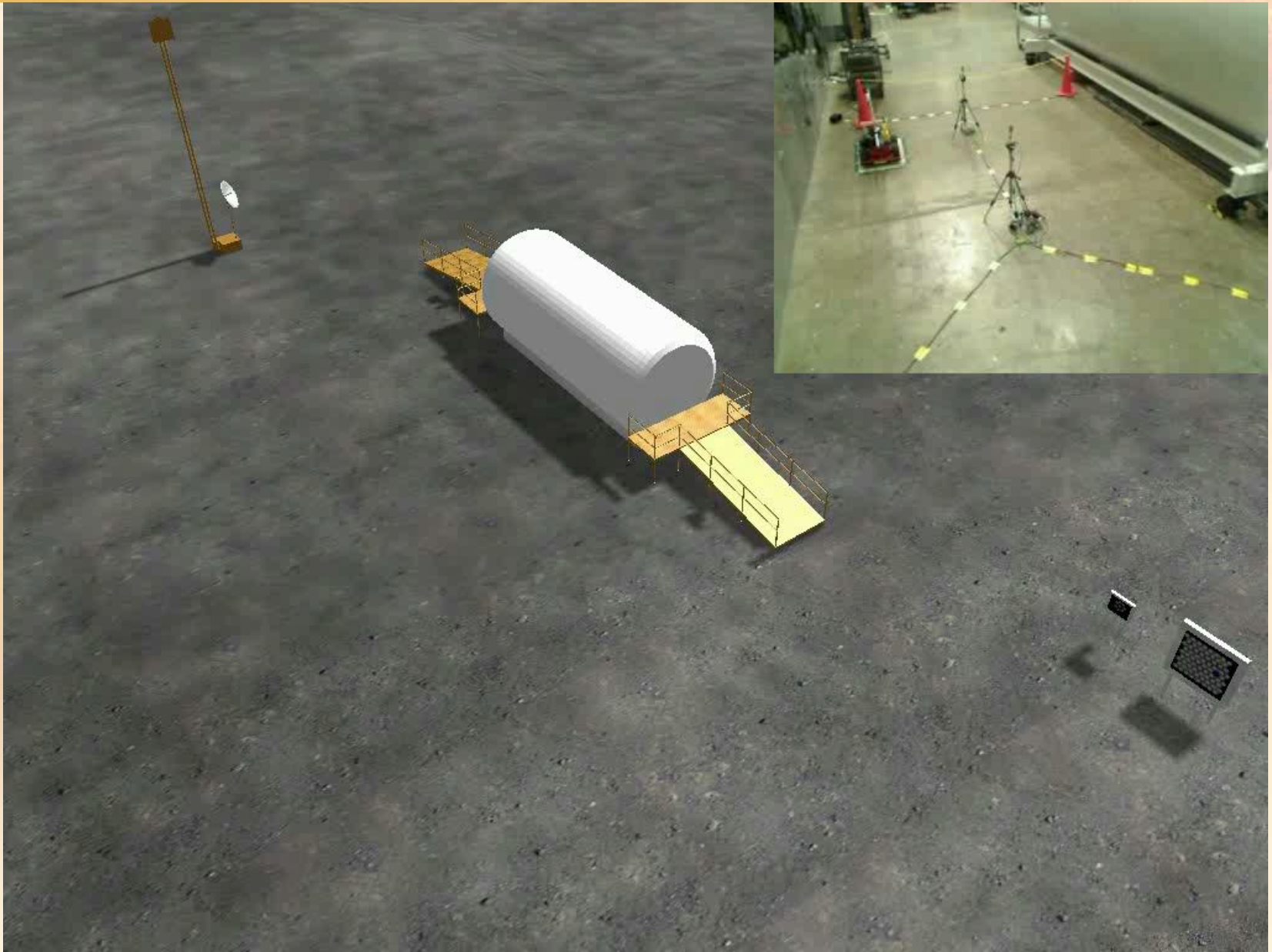
Solar System Internet (SSI)

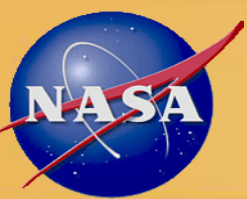
Characteristic	Terrestrial Internet	Solar System Internet
End-to-end Connectivity	Continuous	Frequent Disconnections
Propagation Delay	Short	Long (IP times out)
Transmission Reliability	High	Low
Link Data Rate	Symmetric	Asymmetric
Protocol	TCP/IP, UDP/IP	Bundle Protocol (BP), BP over IP

- **Delay Tolerant Networking (DTN) refers to a wide range of challenged networks, where**
 - End-to-End connection cannot be assumed to exist
 - Network Partitioning is Frequent
 - Delay/Disruption Can (Must) be Tolerated
- **Current Projects**
 - Deep Impact Network (DINET) running tests on Deep Impact (EPOXI) simulating Mars Relay
 - U. Colorado/Bioserve running tests on ISS



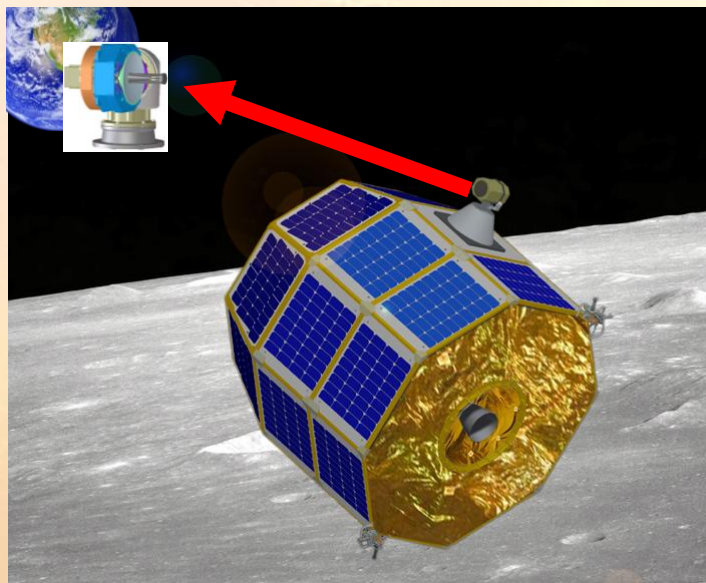
Test of DTN at JSC Hab Mockup



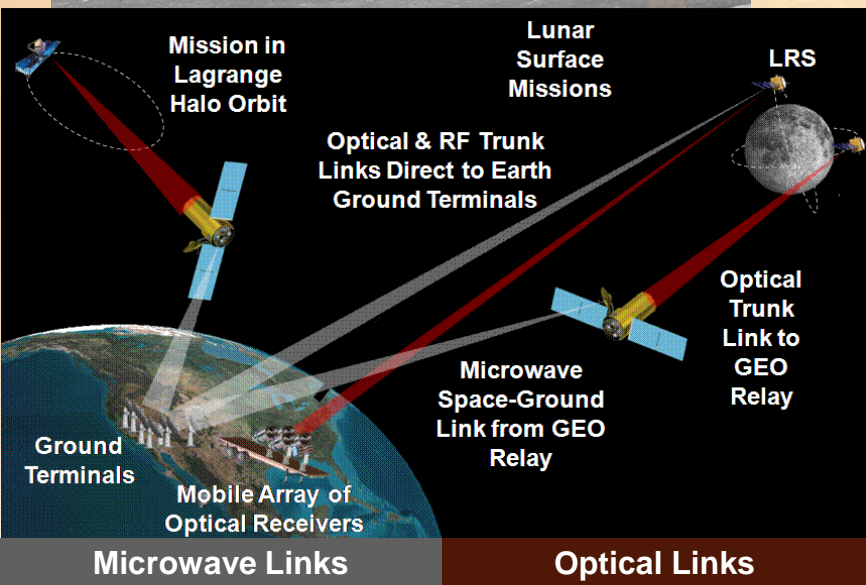


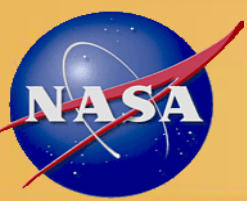
Optical Communications Plans 2020

LLCD on LADEE: 600 Mbps in 2012

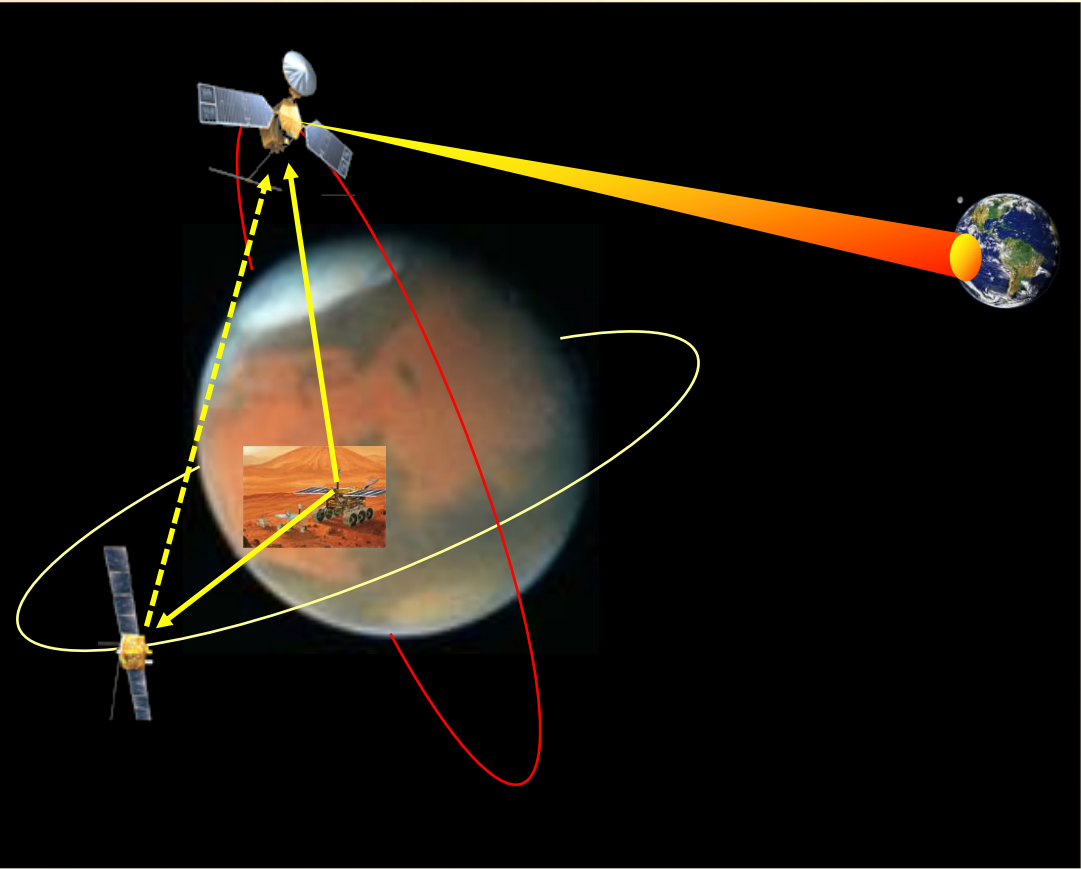


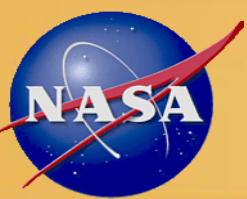
- In partnership with SMD & ESMD, SCaN is flying the Lunar Laser Comm Demonstration (LLCD) on the Lunar Atmosphere & Dust Environment Explorer (LADEE) mission in 2012
 - Earth-based photon-counting technology
 - Transmits 600 Mbps from moon
 - Passed Preliminary Design Review (PDR) in June
- More demos planned in 2013-2016
- Operational laser comm planned to support Human Lunar Exploration & near-Earth Science by 2020





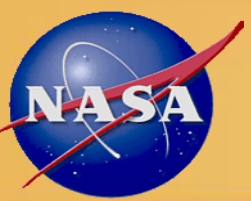
Optical Communications Plans 2025+

- Operational laser comm for Mars science & exploration planned for ~2025
- 
- The diagram illustrates a Mars optical communication system. It shows Mars in the center with two orbiting spacecraft. A yellow beam of light connects one spacecraft to Earth, which is shown as a small globe on the right. A dashed yellow line connects the two spacecraft, and a red line shows the orbit of one of the spacecraft. An inset image shows a Mars rover on the surface.
- 100 Mbps from 1 AU
 - 30 Mbps from 2.2 AU
 - *HDTV from Mars!*
 - 30 cm / 10 W Deep Space Terminal
 - Key Decision Point-A in 2010
 - Ground terminal with photon-counting technology
 - 60 Kg, 160 W



Summary

- **Space Communication & Navigation, Mars Exploration, and Constellation Programs are working together to define the architecture, technologies, & evolution path to support anticipated Science and Exploration missions to 2030 & beyond**
- **Future Mars architecture = Future Lunar architecture (with known differences, e.g., spectrum)**
- **Technologies to realize Mars architecture are being developed & tested today**
- **Future high bandwidth capacity enables huge expansion of science, streaming HDTV, & Solar System Internet ... *from Mars!***



Mars Design Reference Architecture 5.0

**Now available on the Exploration Systems Mission
Directorate web site:**

http://www.nasa.gov/exploration/library/esmd_documents.html